Physical Variables used in MHD Simulations

The **basic plasma and electrodynamic field variables** (written by each MHD model) are:

- Mass density **Rho** or particle number density **N**.
- Plasma pressure **P**.
- Plasma velocity **V** with its three components **V_x**, **V_y** and **V_z**.
- Magnetic field **B** with its three components **B_x**, **B_y** and **B_z**.
- **B1**
  - SWMF/BATSRUS model: this is the difference between **B** and the Earth's dipole field (components **B1_x**, **B1_y**, **B1_z**).
    B1 is used to see small variations of **B** near the Earth.
  - UCLA-GGCM/OpenGGCM: B1 is the magnetic field as stored on the original model grid on grid cell faces.
    Each B1 component exists on a grid that is offset from the "plasma" grid (where N, T, V are defined) by half a grid position in the direction of the respective field component (i.e., the grid for $B1_x$ is offset in X, the grid for B_y is offset in Y, and the grid for $B1_z$ is offset in Z).
    When using componentds of **B1** for field line tracing, the original grid positions are used for improved accuracy instead of using B field values interpolated onto the plasma grid before performing interpolations during field line tracing (when using components of **B**).
- **BA** is the "B-field anomaly", the difference between the total field strength **B** and the strength of the Earth's dipole field $\mathbf{B_{dipole}}$.
- Electric current density **J** with its three components **J_x**, **J_y** and **J_z**.

Primary variables witten occasionally or by some models only:

- Internal Energy **En.** (P/(γ-1) with γ="ratio of specific heats", usually 5/3).
- Resistivity **Eta** (some runs).

Derived quantities
Note: everything listed here and below is calculated by CCMC.
Please report errors to us.

- **New:** Vector components in spherical coordinates for models with cartesian grids.
  For example **V_r**, **V_t**, **V_p**: plasma velocity in the radial, theta and phi direction, respectively.
  Note: The theta component flips sign around the polar axis of the spherical coordinate system (at X=0 and Y=0).
  Spherical components are available for vectors (**B**, **B1**, **V**, **J**, and **E**) that exist in primary model outputs.
- B-parallel electric current density **J_par** with its three components **J_par_x**, **J_par_y** and **J_par_z**.
  Note: flow line tracings do not make much sense with this vector!
- Electric field **E** with its three components **E_x**, **E_y** and **E_z**.
- **Plasma-β**: "beta"=P/($B^2/2\mu_0$).
- **Plasma Frequency:**
  - $\omega_{pi} = 1.32*10^3*(N\ [cm^{-3}])^{1/2}$ - ion plasma frequency
  - $\omega_{pe} = 5.64*10^4*(N\ [cm^{-3}])^{1/2}$ - electron plasma frequency

  We assume $N=N_e=N_i$ (electron-proton plasma).

The underscore ("_") indicates subscript level in variable name used in plots.

Gradients and divergences (magnetosphere models SWMF/BATSRUS and OpenGGCM only at this time):

- **Vorticity** "omega" (curl of V) with components "omega"$_x$, "omega"$_y$, "omega"$_z$,
- Gradients of selected scalar variables (e.g., gradN, gradT, gradP) and divergences of selected vectors (e.g., div.**V**, div.**ExB**) and curls of vectors can be requested for visualization and ASCII data output.
  A certain discrepancy from expected values can be expected since divergences and gradients are computed based on a finite differencing of data that may have been interpolated before computing the gradient or divergence.
  Vector values in some models may be defined on staggered meshes. For visualization and the computation of

derived quantities (such as ExB) all vector variables are interpolated to cell center positions (where plasma parameters such as N, P, T already reside).

Quantities scaled with radial distance in solar coronal and heliospheric models:

Coordinates: r,lon,lat for MAS, ENLIL and x,y,z for SWMF

- Scaled with r^2:
  N, P, B_r, JxB, E.J (if currents J are available)
- Scaled with r^1:
  B (B_lon,B_lat or B_x,B_y,B_z),
  E (E_r,E_lon,E_lat or E_x,E_y,E_z),
  J (J_r,J_lon,J_lat or J_x,J_y,J_z),
  J_par(J_par_r,J_par_lon,J_par_lat or J_par_x,J_par_y,J_par_z)
- Not scaled:
  T, beta, S (entropy), V (V_r,V_lon,V_lat or V_x,V_y,V_z)

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